SECTION X

Various and manifold is the harvest of diseases reaped by certain workers from the crafts and trades that they pursue; all the profit that they get is fatal injury to their health. . . .mostly, from two causes. The first and most potent is the harmful character of the materials that they handle. . .the second cause I ascribe to certain violent and irregular motions and unnatural postures of the body, by reason of which the natural structure of the vital machine is so impaired that serious diseases gradually develop therefrom.

—Ramazzini

PHYSICAL HAZARDS

The properties, biological effects, and health hazards associated with physical agents are discussed in this chapter. A physical agent can be defined as an entity without substance (i.e., with minimal matter), yet capable of affecting the biological mechanisms of an exposed worker. The hazards considered are those associated with exposure to the following agents, which will be grouped into three classes for discussion.

RADIATION: ionizing radiation and nonionizing radiation, including ultraviolet, visible, infrared, microwave, radio frequency, and laser.

ATMOSPHERIC VARIATIONS: heat, cold, air pressure.

OSCILLATORY VIBRATIONS: noise, vibration.

Some of these agents are encountered only in specific occupational situations while others may be present in a number of working environments.

RADIATION

Eugene Moss, William Murray, Wordie Parr, Ph.D.
and David Conover, Ph.D.

Radiation is energy which is emitted, transmitted, or absorbed in wave, or energetic particle, form. One can think of the wave as the disturbance that transfers energy progressively from one point to another point in a medium.

The electromagnetic (EM) waves consist of electric and magnetic forces. When these forces are disturbed, EM radiation results. The known EM radiations are grouped into a spectrum according to their frequency and/or wavelength (Table 7). The spectrum consists of a continuum of radiation ranging from below radio frequencies to above ionizing; it includes microwave, infrared, visible, and ultraviolet radiation. Although no range of radiation is sharply delineated from another and, in fact, the ranges often overlap, it is convenient to separate these ranges into the above groups because of the physical and biological effects associated with each radiation type.

The range of biological effects of exposure within the EM spectrum is extremely broad and diverse. This is further emphasized by noting the frequency bandwidth covered by the spectrum. Table 7 indicates the band width to encompass at least 10^7 but, in fact, it extends to a factor of 10^{22} Hz. The amount of energy absorbed by the worker varies considerably over this range. The safety, health, evaluation, and control problems associated with such a range of magnitudes are great. No other area in human research has a similar wide range of the hazards that need to be considered, classified, and regulated.

Table 7. Characteristics and sources of electromagnetic radiation.

Type of radiation	Frequency range (Hz)*	Wave length range**(m)	Energy per photon range (eV)†	Typical industrial sources of exposures	Estimated number of exposed workers
A. IONIZING X-ray γ-ray B-ray γ-particle Proton Neutron	$>3.0\times10^{15}$	$<1.0\times10^{-7}$	$>1.2\times10^{1}$	Electronic tubes, radiography, nuclear power plants, radiation curing, medical uses, uranium mining, sterilization processes.	7×10^{6}
B. NONIONIZING					
Ultraviolet	7.5×10^{14} to 3.0×10^{15}	1.0×10^{-7} to 4.0×10^{-7}	3.1 to 1.2×10^{1}	Lamps, welding arcs, gas discharge tubes.	86×10^{6}
Visible	4.0×10^{14} to 7.5×10^{14}	4.0 to 7.6×10^{-7}	1.6 to 3.1	Lamps, welding arcs, hot bodies.	96×10^{6}
Infrared	3.0×10^{11} to 4.0×10^{14}	7.6×10^{-7} to 1.0×10^{-3}	1.2×10^{-3} to 1.6	Lamps, welding arcs, hot bodies.	26×10^{6}
Microwaves	3.0×10^{8} to 3.0×10^{11}	1.0×10^{-3} to 1.0	1.2×10^{-6} to 1.2×10^{-3}	Klystron, magnetron.	14×10^{6}
Radio Frequencies	$<3.0\times10^{8}$	>1.0	$<1.2\times10^{-6}$	Plastic sealers, furniture glue.	7×10^{6}

*Hz = Hertz, cycle per second. **m = meter. †eV = electron volts. Note: The given ranges are only approximations.

IONIZING RADIATION

Ionizing radiation has always been a part of man's natural environment, and since the discovery of X-rays and radioactivity, it has become a part of the industrial environment of many workers. The different types of ionizing radiation vary in their penetrative powers as well as in the number of ions they produce in traversing matter. The latter is important in that biological effects vary with ion density (the number of ions produced per unit length of track).

Ionizing radiations are produced naturally by the decay of radioactive elements or artificially by such devices as X-ray machines and high energy accelerators. A radioactive nucleus is one that spontaneously changes to a lower energy state, emitting particles and often gamma rays in the process. The particles commonly emitted are alpha particles and beta particles. High energy accelerators can produce all of the above particles plus protons, neutrons, and X-rays. The following sections describe some of the more commonly encountered types of ionizing radiation.

Alpha particles, which interact readily with matter to produce ions, usually have energies of from 4 to 8 million electron volts (Mev). They travel a few centimeters in air and up to 60 microns into tissue. The high energy and short path result in a dense tract of ionization along the path of the particles, which produces serious biologic damage in the tissues with which the particles interact. Alpha particles will not penetrate the stratum corneum of the skin and thus are not an external hazard; but if alpha-emitting elements are taken into the body by inhalation or ingestion, serious internal exposure problems may result.

Beta particles interact much less readily with matter than do alpha particles and will travel up to a few centimeters into tissue or many meters in air. Exposure to external sources of beta particles is potentially hazardous, but exposure internally is more hazardous.

Protons with energies of a few Mev are produced by high-energy accelerators and are quite effective in producing tissue ionization. The path length of a proton is somewhat longer than the path of an alpha particle of equivalent energy.

Gamma rays and X-rays are electromagnetic radiations with similar properties. X-rays, in general, have longer wave lengths, lower frequencies, and, therefore, lower energies than gamma rays. Gamma rays are produced by nuclear processes, while X-rays may result from the electronic structure of the atoms or from the slowing down of high-speed electrons. X-rays and gamma rays are primarily an external hazard and their biologic effects are better known than those of any of the other ionizing radiations. Examples of gamma emitters used in industry are cobalt-60, cesium-137, and iridium-192. X-rays may also be encountered during the manufacture and use of electronic tubes and electron microscopes.

Neutrons have about the same mass as protons, but react much differently since they are electrically neutral. These uncharged nuclear particles upon collision with matter may cause the release of all the above types of ionizing radiation. Neutrons can be produced up to several Mev by reactors, accelerators, or certain beryllium-enriched sources.

ROUTES OF ENTRY

The conditions presented by external radiation sources are entirely different from those presented by internal radiation sources which have been deposited in the body, with their attendant continuous irradiation of cells and tissue.

Entry of radiation sources into the body during occupational exposures is principally from breathing air containing particulate or gaseous radionuclides, although ingestion and skin absorption can be important.

Implantation under the skin may occur as the result of accidental skin puncture or laceration. Once inside the body, radionuclides are absorbed, metabolized, and distributed throughout the tissues and organs according to the chemical properties of the elements and compounds in which they exist. Their effects on organs or tissues depend on the type and energy of the radiation and residence time.

The effect from external radiation sources depends on the penetrating ability of the particular radiation. Thus, alpha radiation is of no concern externally, and beta is stopped in the outer tissues, the depth depending on energy. Very low energy X- or gamma radiation is attenuated quite rapidly.

HARMFUL EFFECTS

The early experience of radiation workers (including various nuclear accidents, exposure of radium dial-painters, casualties from atomic bomb explosions) and data from research projects provide clear evidence that high levels of ionizing radiation definitely create somatic damage and may induce genetic damage. The occupational somatic effects include radiodermatitis, epilation, acute radiation syndrome, cancer, leukemia, cataracts, sterility, and life span shortening. The genetic effects resulting from occupational exposures are to a great extent still unknown. Moreover, it is important to remember that a mutation produced by radiation is similar to one effected by a mutagenic chemical or to one occurring spontaneously.

In general, the sequence of events following radiation exposure may be classified into three major periods. The first period is the latent period, defined as the time lapse between the initial radiation event and the first detectable effect. Since the latent period can range from days to years, it is often divided into short-term (days or weeks) and long-term (months or years) effects. The second period, the period of demonstrable effects, occurs immediately after the latent period and is that time period when certain discrete biological effects can be observed. The final period is the recovery period.

The effects from occupational exposure to ionizing radiation are usually localized, leading to erythema or radiodermatitis. An acute radiation syndrome (ARS) episode occurs very rarely. An episode of this type involves whole body exposure exceeding 100 roentgens given in a very short time.

Initial symptoms of ARS are nausea, vomiting, diarrhea, weakness, and shock. Following a latent period of 2 to 14 days, symptoms of fever and malaise occur. During this same period of time, hemorrhagic lesions of the skin often appear, and by the third week, epilation occurs. Painful ulceration, both internal and external, may appear over the whole body and bloody diarrhea may occur. Death may result from severe bone marrow depression if the radiation exposure level is high. The patient is also susceptible to infection of many types.

Among the long term effects are an increased incidence of carcinoma, as noted in the radium dial painters and uranium miners; the embryological effects, as noted in pregnant working women; the cataractogenic effects, as seen in certain radiologists and nuclear physicists; and shortening of the life span.

Overexposure of a worker to either an external or internal source of radiation creates a medical emergency. In serious situations involving a release of radioactive material, the degree of contamination must be determined before the individual can be admitted to a hospital. A much more detailed discussion of the medical aspects of radiation accidents is available in the volume by Saenger (1963) listed in the bibliography that follows.

POTENTIAL OCCUPATIONAL EXPOSURES

With the widespread use of radioactive isotopes in industry and the increasing use of X-ray sources, ionizing radiation exposures may occur in a wide variety of occupations. The following examples show the diversity of occupations potentially exposed to ionizing radiation.

Aircraft workers
Atomic energy plant workers
Biologists
Cathode ray tube makers
Ceramic workers
Chemists
Dental Assistants
Dentists
Dermatologists
Drug makers
Drug sterilizers
Electron microscope makers
Electron microscopists
Electrostatic eliminator operators
Embalmers
Fire alarm makers
Food preservers
Food sterilizers
Gas mantle makers
High voltage television repairmen
High voltage vacuum tube makers
High voltage vacuum tube users

Industrial fluoroscope operators
Industrial radiographers
Inspectors using, and workers in proximity to, sealed gamma ray sources (cesium-137, cobalt-60, and iridium-192)
Klystron tube operators
Liquid level gage operators
Luminous dial painters
Machinists, fabricated metal product
Military personnel
Nurses
Oil well loggers
Ore assayers
Pathologists
Petroleum refinery workers
Physicians
Physicists
Pipeline oil flow testers
Pipeline weld radiographers
Plasma torch operators
Plastic technicians
Prospectors
Radar tube makers
Radiologists
Radium laboratory workers
Radium refinery workers
Research workers
Television tube makers
Thickness gage operators
Thorium-aluminum alloy workers
Thorium-magnesium alloy workers
Thorium ore producers
Tile glazers
Uranium dye workers
Uranium mill workers
Uranium miners
Veterinarians
X-ray aides
X-ray diffraction apparatus operators
X-ray technicians
X-ray tube makers

BIBLIOGRAPHY

Albert, R. E., and A. R. Omran. 1968. Follow-up study of patients treated by X-ray epilation for tinea capitis. Arch. Environ. Health 17:899-934.

Bithell, J. F., and A. M. Stewart. 1975. Pre-natal irradiation in childhood malignancies: a review of British data for the Oxford Survey. Br. J. Cancer 31:271-287.

Bross, I., and N. Natarajan. 1972. Leukemia from low-level radiation: identification of susceptible children. N. Eng. J. Med. 2:1327-1332.

Court Brown, W., and R. Doll. 1965. Mortality from cancer and other causes after radiotherapy for ankylosing spondylitis. Br. Med. J., 2:1327-1332.

Diamond, E., H. Schmerler, and A. Lilienfeld. 1973. The relationship of intrauterine radiation to subsequent mortality and development of leukemia in children. Am. J. Epidemiol. 97:283-313.

Ford, D., J. Patterson, and W. Treuting. 1959. Fetal exposure to diagnostic X-rays, and leukemia and other malignant diseases in childhood. J. Nat. Cancer Inst. 22:1093-1104.

Glass, R. 1966. Mortality of New England Dentists, 1921-1960. PHS Pub. No. 999-RH-18, Washington, D.C.

Graham, S., M. L. Levin, A. M. Lilienfeld, L. M. Schuman, R. Gibson, J. Dowd, and L. Hempelmann. 1966. Preconception, intrauterine, and postnatal irradiation as related to leukemia. Nat. Cancer Inst. Monogr. 19:347-371.

Hempelmann, L., J. Pifer, G. Burke, R. Terry, and W. Ames. 1967. Neoplasms in persons treated with X-rays in infancy for thymic enlargement. A report of the third follow-up survey. J. Nat. Cancer Inst. 38: 317-341.

Hempelmann, L. 1968. Risk of thyroid neoplasms atfer irradiation in childhood. Science 160:159-163.

Hempelmann, L., and J. Grossman. 1974. The association of illnesses with abnormal immunologic features with irradiation of the thymic gland in infancy: A preliminary report. Radiat. Res. 58:122-127.

Hempelmann, L., W. Hall, M. Phillips, R. Cooper, and W. Ames. 1975. Neoplasms in persons treated with X-rays in infancy: fourth survey in 20 years. J. Nat. Cancer Inst. 55:519-530.

Jablon, S., and H. Kato. 1971. Mortality among A-bomb survivors 1950-1970. Atomic Bomb Casualty Commission Technical Report No. 10. Available from the National Technical Information Service, U. S. Department of Commerce, Pub. No. ABCC-Tr-10-71, Springfield, Virginia 22161.

Jablon, S. 1973. The Origin and Findings of the Atomic Bomb Casualty Commission. DHEW Pub. No. (FDA) 73-8032, Washington, D.C.

MacKenzie, I. 1965. Breast cancer following multiple fluoroscopies. Br. J. Cancer. 19:1-8.

MacMahon, B. 1962. Prenatal X-ray exposure and childhood cancer. J. Nat. Cancer Inst. 32:1173-1191.

Matanoski, G., R. Seltzer, P. Sartwell, E. Diamond, and E. Elliott. 1975. The current mortality rates of radiologists and other physician specialists: deaths from all causes and from cancer. Am. J. Epidemiol. 101:188-198.

Matanoski, G., R. Seltzer, P. Sartwell, E. Diamond, and E. Elliott. 1975. The current mortality rates of radiologists and other physician specialists: specific causes of death. Am. J. Epidemiol. 101:199-210.

Matanoski, G. 1973. Cancer risk increased in radiologists. Johns Hopkins Gazette 3:1-2.

Meyer, M., and J. Tonascia. 1973. Possible effects of X-ray exposure during fetal life on the subsequent reproductive performance of human females. Am. J. Epidemiol. 98:151-160.

Meyer, M., J. Tonascia, and T. Merz. 1975. Long-term effects of prenatal X-ray on development and fertility of human females. In International Symposium on Biological Effects of Low Level Radiation Pertinent to Protection of Man and His Environment. Chicago, November 3-7.

Modan, B., D. Baidatz, H. Mart, R. Steinitz, and S. Levin. 1974. Radiation induced head and neck tumors. Lancet 1:277-279.

National Academy of Sciences — National Research Council. 1972. The effect on populations of exposure to low levels of ionizing radiation. A report of the Advisory Committee on Biological Effects of Ionizing Radiation, Washington, D.C.

Natarajan, N., and I. Bross. 1973. Preconception radiation and leukemia. J. Med. 4:276-281.

Oppenheim, B., M. Griem, and P. Meier. 1974. Effects of low-dose prenatal irradiation in humans: analysis of Chicago lying-in data and comparison with other studies. Radiat. Res. 57:508-544.

Saenger, E. L., ed. 1963. Medical Aspects of Radiation Accidents. U.S. Atomic Energy Commission. Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Seltzer, R., and P. Sartwell. 1965. The influence of occupational exposure to radiation on the mortality of American radiologists and other medical specialists. Am. J. Epidemiol. 81:2-22.

Sigler, A., A. Lilienfeld, B. Cohen, and J. Westlake, 1965. Radiation exposure in parents of children with mongolism (Down's syndrome). Bull. Johns Hopkins Hosp. 117:374-399.

Silverman, C., and D. Hoffman. 1975. Thyroid tumor risk from radiation during childhood (Overview). Prev. Med. 4:100-105.

Stewart, A., J. Webb, and D. Hewitt. 1958. A survey of childhood malignancies. Br. Med. J. 1:1495.

Stewart, A., W. Pennybacker, and R. Barber. 1962. Adult leukemia and diagnostic X-rays. Br. Med. J. 2:882-890.

Stewart, A., and G. Kneale. 1970. Radiation dose effects in relation to obstetric X-rays and childhood cancers. Lancet 1:1185-1188.

Uchida, I., and E. Curtis. 1961. A possible association between maternal radiation and mongolism. Lancet 11:838-850.

Uchida, I., R. Holunga, and C. Lawler. 1968. Maternal radiation and chromosomal aberrations. Lancet, 11:1045-1049.

ULTRAVIOLET RADIATION

Ultraviolet (UV) radiation is an invisible radiant energy produced naturally by the sun and artificially by arcs operating at high temperatures. Artificial sources commonly found in industry are germicidal and black-light lamps, carbon arcs, welding and cutting torches, electric arc furnaces, and laboratory equipment.

Since the eyes and skin readily absorb UV radiation, they are particularly vulnerable to injury. The severity of radiation injury depends on factors which include exposure time, intensity of the radiation source, distance from the source, wavelength, sensitivity of the individual, and presence of sensitizing agents.

HARMFUL EFFECTS

Sunburn (erythema) is a common example of the effect of UV radiation on the skin. Repeated UV exposure of lightly pigmented individuals may result in actinic skin — a dry, brown, inelastic, wrinkled skin. There are telangiectases on the forehead, and neck movements produce lines on the nape in an angular pattern. Actinic skin is not harmful in itself, but it is a warning that conditions such as senile keratosis, squamous cell epithelioma, and basal cell epithelioma may develop.

Since UV radiation is not visible, the worker may not be aware of the danger at the time of exposure. Absorption of the radiation by the mucous membranes of the eye and eyelids can cause conjunctivitis (commonly known as "ground glass eyeball" or "welder's flash"). Lesions may also be formed on the cornea at high exposure levels (photokeratitis). Such injuries usually manifest themselves 6 to 12 hours after exposure. The injuries may be very painful and incapacitating, but impairment is usually temporary.

Photosensitizing agents have action spectra which are frequently in the ultraviolet range (Table 8). Some drugs and many plants, including figs, limes, parsnips, and pink-rot celery, carry photosensitizing chemicals believed to be furocoumarins and psoralens. Symptoms upon contact are those of an exaggerated sunburn with blisters frequently present. The most important industrial photosensitizer is coal tar which has an action spectrum in the visible range.

Ultraviolet light can also act in a nonspecific manner in the production of herpes simplex and chronic discoid lupus erythematosus.

PERSONAL PROTECTIVE METHODS

Protective measures are essential for workers exposed to high-intensity UV sources. Goggles, face shields, and masks provide protection for the eyes; protective clothing and barrier creams minimize skin exposure. Shiny metal surfaces reflect UV radiation and, when possible, should be removed from the work area. Reflections from lamp housings, walls, ceilings, and other surfaces should be reduced by coating these surfaces with a pigmented paint of low UV reflectance. Operations that produce high levels of UV should be placed behind enclosures to absorb the radiation and shield nearby workers from exposure.

POTENTIAL OCCUPATIONAL EXPOSURES

UV radiation exposure is generally present wherever occupations involve sunlamps, the outdoor sun, welding arcs, plasma torches, lasers, laboratory research, printing processes, drying and curing processes, nondestructive testing, environmental test chambers, medical devices and materials, and chemical processing and manufacturing. Occupations associated with potential UV radiation exposure include the following:

Agricultural workers
Bacteriologists
Bath attendants
Beauty salon workers
Brick masons
Cattlemen
Chemists
Construction workers
Dentists
Farmers
Fishermen
Food irradiators
Gardeners
Graphic illustrators
Greenskeepers
Horticultural workers
Laboratory workers
Lamp testers
Landscapers
Lifeguards
Lithographers
Lumberjacks
Maintenance workers
Meat curers
Metal casting inspectors
Microscopists
Military personnel
Movie projectionists
Nurses
Oilfield workers
Open pit-miners
Opticians
Optometrists
Outdoor maintenance workers
Paint and color testers
Paint curers
Physicians
Physicists
Physiological optics workers
Photo-bacteriologists
Phototherapy technicians
Pipeline workers

Table 8. Some examples of action spectra of normal and abnormal reactions in man.*

Condition	Wavelength Range (nm)	Maximum Reaction (nm)
Normal sunburn	290-320	297-307
Artificial light sources	250-320	250
Melanin pigmentation	290-320 320-480	290-310
Vitamin D production	290-310	290
Hyperbilirubinemia of prematurity	Blue visible spectrum	440-470
UV carcinogenesis	290-320	290-310
Solar urticaria	290-320 320-400 400-600	varying
Porphyria photosensitivity	380-600	400-410
Xeroderma pigmentosum	290-340	293-307
Polymorphic photodermatitis	290-320 320-400	290-320
Lupus erythematosus (LE) and discoid LE	290-320	
Solar (actinic) degeneration	290-400	?
Photoallergic reactions to halogenated salicylanilides and other related compounds	320-380	330-360
Phototoxic reactions to drugs	320-400 290-320	320-400
Psoralens (8-methoxy- and trimethylpsoralen)	320-380	330-360

*Used with permission from Sunlight and Man. T. B. Fitzpatrick et al., eds. Table 4. University of Tokyo Press, Tokyo, Japan.

Plasma torch operators
Plastic curers
Policemen (including crossing guards)
Postmen
Printers
Production workers in chemical processing
Railroad track workers
Road workers
Seamen
Ski instructors
Space simulator workers
Sportsmen
Surveyors
Textile inspectors
Tissue culture workers
Tobacco irradiators
Vitamin D synthesis workers
Welders
Welder foremen
Wood curers

VISIBLE RADIATION

Visible radiation, or light, from either the sun or artificial sources, is probably one of the more important occupational health considerations because of its major role in our daily life. Only within the last few years have investigators begun to discover various subtle physiological and biochemical responses to light.

Several human systems respond directly or indirectly to visible radiation. A direct effect has been defined as a chemical change in the composition of a tissue resulting from the absorption of light energy within the tissue. Because few direct effects of light have been documented, light is not considered a major occupational health hazard.

Indirect effects of light, however, can occur — not from absorption of light energy in tissues — but from the action of chemical signals liberated by cells in the body. Examples of this relationship of light to biological rhythms, include physical activity, sleep, food consumption, etc. Another well-known indirect effect is the inhibition of melatonin synthesis by the pineal gland which in turn affects maturation and activity of the sex gland. The various known classifications of abnormal biological reactions to light are shown in Table 9.

HARMFUL EFFECTS

One of the controversial issues associated with visible radiation is the effect of illumination on job performance. The concept exists that the levels of illumination and source luminance routinely encountered in interior working environments may constitute some type of an ocular health hazard. Studies on humans gazing at the sun and on rats and mice under common interior lighting intensities have produced evidence to indicate a hazard; these studies, however, have not been considered conclusive and the results have been disputed.

At the 1974 NIOSH symposium on illumination, several conclusions were agreed upon:

1) High levels of lighting can cause damage to the eye, i.e., retinal or macular degeneration.
2) Poor lighting conditions can cause aesthenopia.

3) With the possible exception of miner's nystagmus, such organic diseases as glaucoma, cataracts, and retinal degeneration do not result from exposure to low levels of illumination.

The consensus seemed to be that if there is sufficient illumination to perform a task reasonably well, then there is sufficient light to meet the safety criteria.

Although the etiology of asthenopia (eye strain) is debatable, it appears that repeated occurrences probably do not lead to any permanent eye damage. Workers over 40 years of age will probably encounter more symptoms of asthenopia (headache, tired eyes, irritation) since they require more light to perform a similar job than younger workers.

POTENTIAL OCCUPATIONAL EXPOSURES

Virtually all occupations offer exposure to the potential hazards of defective illumination. Some occupations, however, require unusually close, fine work and attention to detail for many hours a day. Some of these occupations are:

Draftsmen	Jewelers
Electronic equipment assemblers	Quality control inspectors
Engravers	Watchmakers

INFRARED RADIATION

All objects having temperatures above absolute zero emit infrared radiation (IR) as a function of temperature. In biological systems the major insult of IR occurs as a result of a rise in temperature of the absorbing tissue.

The physical factors associated with temperature rise are the wavelength, heat conduction parameters, exposure time, and total amount of energy delivered to the exposed tissue. Since IR photons are low in energy, they probably do not enter into photochemical reactions with biological systems. Molecular interaction with radiation in the IR regions are characterized by various vibrational-rotational transitions resulting in an increase in thermal energy of the molecule.

HARMFUL EFFECTS

Since the primary effect of IR on biological tissues is thermal, the skin provides its own warning mechanism by having a pain threshold below that of the burn threshold.

In the eye, however, there is no adequate warning mechanism to protect against lenticular damage. Cataracts may be produced by prolonged exposure to wavelengths at energy levels that do not normally burn the skin. The classic ocular effect observed after many years of IR exposure is a posterior cataract, sometimes called glassblower's or furnaceman's cataract. This type of cataract has a lengthy latent period (10 to 15 years) in individuals chronically exposed to IR which has made it difficult to determine threshold values.

The present etiology of IR-induced cataracts is thought to be directly correlated with the amount of energy initially absorbed by the iris and then transferred to the lens. The threat of cataract formation is primarily from wavelengths below 1400 nanometers. Longer wavelengths may produce corneal damage, the difference being due to the site of energy absorption.

The primary biological effect of IR on the retina and choroid is thermal in nature, with the amount of damage being proportionate to the length of exposure. If the radiation intensity is low enough, however, the normal retinal blood flow may be sufficient to dissipate any heat generated. Nevertheless, due to the focusing effect of the anterior ocular components, small amounts of IR radiation can produce a relatively intense point energy distribution on the retina resulting in a lesion. The effects of IR on the lid and cornea can be considered as ordinary cutaneous burns.

POTENTIAL OCCUPATIONAL EXPOSURES

A wide range of IR wavelengths representing large variations in temperature is encountered in many industries from direct (lamps) and indirect (heat) sources. Occupations potentially associated with infrared radiation exposures include the following:

- Bakers
- Blacksmiths
- Braziers
- Chemists
- Cloth inspectors
- Cooks
- Dryers, lacquer
- Electricians
- Firemen, stationary
- Foundry workers
- Furnace workers
- Gas mantle hardeners
- Glass blowers
- Glass furnace workers
- Heat treaters
- Iron workers
- Kiln operators
- Laser operators
- Motion picture machine operators
- Plasma torch operators
- Skimmers, glass
- Solderers
- Steel mill workers
- Stokers
- Welders

MICROWAVE/RADIOFREQUENCY RADIATION

Various estimates have been made of the number of workers potentially exposed to microwave/radio frequency (RF) radiation sources in industry, including one estimate of approximately 21 million workers at risk (See Reference 110). Obviously, not every worker in every job is exposed to hazardous microwave/RF radiation levels, but an exposure of even 25 percent of the workers potentially at risk would still present a significant target population. Because of the size of this potentially exposed group at work, the continuing expansion of microwave use in industry, and the lack of widely known bioeffects data, a list of references is offered in citations to the material presented. Also the following

Table 9. Classification of abnormal reactions to light in man.*

Type	Light Alone	Light + Exogenous Agent	Light + Metabolite	Light + Abnormal Skin or Disease
Genetic	Ephelides (freckles)		Porphyrias: Erythropoietic porphyria; Erythropoietic protoporphyria; Variegate porphyria (mixed porphyria); Hereditary coproporphyria	Xeroderma pigmentosum Hartnup syndrome Oculocutaneous albinism Cockayne's syndrome Rothmund-Thomson syndrome Hailey-Hailey disease Vitiligo Darier-White disease Bloom's syndrome Phenylketonuria(?)
Chemical, phototoxic		Topical and oral drugs Phytophotodermatitis		
Chemical, photoallergic		Topical and oral drugs		
Chemical induction of disease		Lupus erythematosus from sulfonamides, hydralazine, reserpine, griseofulvin, oral contraceptives, etc.	Porphyria from hexachlorobenzene, estrogens, griseofulvin, stilbesterol, alcohol	
Nutritional				Kwashiorkor; Pellagra
Infectious				Lymphogranuloma venereum Herpes simplex

Table 9. Classification of abnormal reactions to light in man.* (Continued)

Type	Light Alone	Light + Exogenous Agent	Light + Metabolite	Light + Abnormal Skin or Disease
Degenerative and neoplastic	Chronic solar skin damage Solar keratoses Basal cell carcinoma Squamous cell carcinoma Malignant melanoma(?) Connective tissue degeneration (wrinkling) Telangiectasia			
Miscellaneous	Acute solar skin damage (sunburn) Hydroa aestivale and hydroa vacciniforme Disseminated superficial actinic porokeratosis	Phytophotodermatitis	Porphyria cutanea tarda	Lupus erythematosus (cutaneous and systemic) Solar urticaria Polymorphous light eruption Malignant carcinoid Pemphigus foliaceus Dermatomyositis

*Used with permission from Sunlight and Man. T. B. Fitzpatrick et al., eds. Table 1. University of Tokyo Press, Tokyo, Japan.

units of measurement are defined: μWcm^{-2} = microwatts per centimeter squared; MHz = 10^6 Hz; GHz = 10^9 Hz; $V{\cdot}m^{-1}$ = volts per meter; and $A{\cdot}m^{-1}$ = amperes per meter.

HARMFUL EFFECTS

Effects from exposure to microwave/RF radiation due to heating have been well documented, but evidence for those occurring in the absence of a tissue temperature rise is incomplete and in dispute (1-3).

Frey (4) reported an acoustic response which he postulated to be a direct auditory nerve response to microwaves. The phenomenon occurred instantaneously in human subjects exposed to power densities as low as 100 $\mu W{\cdot}cm^{-2}$. This specific effect was perceived as a buzz, ticking, or knocking, depending upon the pulse width and pulse repetition rate. The greatest sensitivity was observed in humans within the frequency range 300 MHz to 1200 MHz. The area directly over the temporal lobe of the brain was identified as the most sensitive area.

More recently Lebovitz (5) proposed that the cochlear hair cell structures within the vestibulo-cochlear complex of the human ear could directly respond to stimulation from pulse modulated microwave radiation. Guy (6) confirmed the reports of human auditory perception of pulse modulated microwave radiation and demonstrated a similar auditory response in cats which disappeared when the fluid was removed from the vestibulo-cochlear complex. Sommer and Von Gierke (7) confirmed the existence of this specific effect but stated that the effect was due to electromechanical transduction rather than direct stimulation of neural fibers or cortical neural tissue.

The possibility that microwave radiation could interact with the central nervous system (CNS) without detectable heating has been suggested by several investigators (8-18). Osipov (12) feels that some of the effects which have not been attributed to heating may in fact be due to microthermal heating. Microthermal heating is very localized and the temperature rise could not be detected by conventional temperature measurement techniques. Contrary to the subjective clinical complaints reported previously, recent studies [Baranski (8)] have used more objective measurements, better controls, improved statistics, a clearer description of the experimental design, and well documented experimental procedures.

In the Soviet and Eastern European literature (19-32), the following symptoms were reported as associated with 10/20-year exposure to microwave/RF radiation: headache, increased suspectibility to fatigue, diminished intellectual capabilities, dullness, partial loss of memory, decreased sexual ability, irritability, sleepiness and insomnia, and emotional instability. Objective disorders include sweating, hypotension, dyspnea, pains in the chest, sinus arrhythmias, bradycardia, and other cardiovascular problems. Electroencephalogram (EEG) recordings and the associated response times have been shown to be altered by microwave/RF exposure. Responses are characterized by initial excitation followed by inhibition. Also noted were threshold shifts generally in the direction of increasing thresholds for sensory perception, increases in the latent period of the condition-reflex reaction, and disruption of vegetative system regulatory and compensatory functions.

Other changes that have been observed are: in the histamine level in the blood (33-36), decreased cholinesterase levels in persons and animals exposed to microwave/RF radiation (37-43); alterations in the protein fractions, ions, histamine content, hormone and enzyme levels, and immunity factors (27,33-37,44-52); leukocytosis (monocytosis, lymphocytosis, and eosinophilia); recticulocytosis; and thrombocytopenia.

Of particular significance are studies of genetic and reproductive system effects because of the possible impact in large populations over long periods of time. One study suggested a possible correlation between paternal radar exposure and mongoloidism of the progeny (53). Several occupational studies have suggested possible disturbances in human reproductive system functions (27,33,54). Animal studies with low intensity exposures report reproductive system disturbances and cases of detrimental effects on the progeny (55-59).

Changes in menstrual patterns, retarded fetal development, congenital effects in newborn babies, decreased lactation in nursing mothers, and an increased incidence of miscarriages for women working with microwaves have been reported [Marha et al. (60,61]. As a result, Czechoslovakian employment practices (60) prohibit women of reproductive capacity from working with RF radiation sources. Teratogenic effects on the fetus of a mother treated with RF radiation at the beginning of pregnancy (62) and impaired embryogenesis in humans and animals, particularly when RF irradiation occurred during the initial stages of pregnancy (63) have been reported. Rubin (64) reported on a case of microwave exposure of the human female pelvis during early pregnancy and prior to conception. The patient was irradiated during the first 59 days of pregnancy and aborted on day 67. The author warned against treating pregnant women with microwave radiation unless a careful menstrual history is taken (64).

Microwave/RF teratogenic effects have been produced in mealworm beetle pupae (65, 66), chick embryos (67,68), rats (69), and mice (70). The teratogenic effects noted in rats (69) were produced following irradiation at the same frequency (27.12 MHz) where the majority of RF power sources operate. A single acute RF exposure for ten minutes at 27.12·MHz between the first and the 16th day of pregnancy was sufficient to produce teratogenic effects in rats (69). The head, palate, limbs, tail, and abdomen were malformed following RF irradiation.

Primigravid mice irradiated at 2450 MHz with an accompanying injection of cortisone on days 11, 12, 13, and 14 of gestation gave birth to greater numbers of stillborn and deformed fetuses (71). Microwave irradiation of white CF1 mice at 2450 MHz with a mean absorbed dose rate of 107 mW/gm for four minutes produced teratogenic effects on gestation days 3, 4, 8, 10, and 12 (72).

One of the more important bioeffects related to temperature rises induced by microwave radiation in biological media is cataract formation (73-81). Kramer et al. (82) concluded that a temperature of at least

41 °C within the rabbit eye behind the lens is needed for cataractogenesis.

Weiter et al. (83) reported that the ascorbic acid content of rabbit lenses is a good index of microwave induced cataracts. The ascorbic acid content of rabbit lenses decreased with increasing microwave irradiation.

Behavioral effects observed after exposure to microwave/RF radiation indicate that the modifications of normal behavior are related to the increased body thermal burden. Thomas et al. (84) observed that a rat's ability to perceive a constant time interval was degraded by irradiation for times sufficient to cause whole body heating. Hunt et al. (85) found that irradiation of rats at 2.45 GHz caused a decrease in their ability to swim a water alley and that errors of omission in performing visual discrimination tests increased immediately following microwave irradiation. Soviet investigators, however, have concluded that behavioral effects are not primarily related to whole body heating (86).

A summary of available information on biologic effects and health hazards was presented in 1974 at an international symposium held in Warsaw, Poland (87).

Radio Frequencies Below 300 MHz

Previously, it was thought that there were no biological effects for frequencies below 300 MHz (0.3 GHz). In 1977, NIOSH, the United States Information Agency (USIA), and the United States Air Force (USAF) funded bioeffects research within the radiofrequency (RF) band which extends from 10 to 300 MHz in order to evaluate the accuracy of the 1977 standards for this frequency band. Both the ANSI C95.1 and the OSHA regulations (88) specify a frequency range from 10 MHz to 100 GHz.

Kall (89,90) studied the effects on rats exposed to RF (6 and 21 MHz) fields, similar to those found in the industrial environment. He noted that the gastrointestinal motor activity increased and cholinesterase activity decreased significantly. From the results of these studies on rats, Kall (90) recommended to the USIA that exposure standards should be modified to specify an electric field strength of 1500 $V \cdot m^{-1}$ and a magnetic field strength of 5 $A \cdot m^{-1}$ for the frequency range from 3 to 30 MHz.

The theoretical data of Lin (91) for a spherical phantom model simulating man has shown that the *magnetic field component* of the RF(1-20MHz) field may be the *most hazardous*. For RF fields close to typical RF power sources, the heating of the theoretical human phantom model due to the magnetic field component can be even larger. These conditions should be carefully considered when attempting to estimate the potential hazard from an RF radiation field.

Bawin (92,93) demonstrated EEG changes in cats and increases in calcium efflux in chicks following exposure to amplitude modulated 147 MHz fields. The amplitude modulation frequency (8-16 MHz) approached that of physiological bioelectric function rhythms. Further examples of alterations in circadian rhythms by RF exposure are effects on the cell division rate of corneal epithelium (94,95) and changes in rate of bone marrow cell mitoses (96).

Prince et al. (97) demonstrated that RF fields (10-27 MHz) can produce a marked increase in lymphocyte mitotic activity 71 hours post-exposure in monkeys. Lovely et al. (98) reported no in vitro lymphocyte mitotic activity 48 hours following RF exposure of monkeys.

Stavinoha et al.(99) reported that near-field exposures of mice to 19 MHz caused definitive changes in lymphocytes and other white blood cells. The number of polymorphonuclear leukocytes was significantly higher and the number of lymphocytes was significantly lower in the irradiated group as compared with that of the control group. These alterations in white blood cells could not be duplicated in animals exposed in a hot air oven which elevated the colonic temperature the same amount as the RF field exposures. Czerski (96) showed alterations in the diurnal rhythm of peripheral white blood cells and granulocyte precursor mitoses in Guinea pig bone marrow. The results suggest a cumulative effect on the lymphatic system associated with decreased antibody production. This would imply that employees exposed to RF radiation might be more susceptible to infection and more susceptible to allergies encountered in the work environment.

The immunosuppressive and anti-lymphocytic actions of the adrenal glucocorticoids are well known. It is possible that immunologic effects caused by microwave/RF fields are related to glucocorticoid levels. Guillet et al. (100) reported the concentration of adrenal glucocorticoids in the blood increased following microwave irradiation.

Bollinger et al. (101) demonstrated that the uptake of H-3 Thymidine by lymphocytes isolated from mice exposed to RF fields ranged from 2.5 to 5 times that of control animals. Frazer (102) reported that the proportion of rat lymphocytes fell to 48.5% following RF irradiation. The total segmenters increased from 27.8 to 46.8%. It is not known whether these results indicate a direct effect on the cell population or an indirect thermal interaction followed by a rapid endocrine response. Froehlich (103) has shown that these effects could occur at the molecular level by either mechanism. Cody et al. (104) demonstrated alterations in the molecular spectra of biologically significant compounds, such as RNA, when exposed to RF radiation.

It is important to consider data which show that the distribution and magnitude of the absorbed power, *hence the expected biological effects,* varied greatly with exposure conditions. Bussey (105) found that the field intensity and distribution are markedly different in rats and primates. Guy et al. (106) measured field distributions in realistic models of man. The distribution of absorbed power in models of man was highly non-uniform with maximum power absorption (and associated localized temperature rises) occurring in the following locations: axilla, gonads, perineum, lateral thorax, ankles, sternum, forearms, tibia and fiibula, knees, neck, clavicle, shoulders and back. Persons industrially exposed to RF have complained of sensations of warming in many of the above mentioned locations.

Research (107-108) has indicated that the maximum amount of microwave/RF radiation is absorbed within the RF frequency range of approximately 25-26 MHz. Thus, consideration of the results of hyperthermia in the anatomical locations specified by Guy (106) should be of great interest.

For microwave/RF bioeffects dependent on power absorption, human RF exposures from approximately 25-26 MHz represent the greatest potential hazard. Industrial RF exposure measurements performed by NIOSH (109,110) show that the vast majority of industrial RF sources operate from 10-40 MHz and that more than 70% of the sources surveyed exceeded applicable personnel RF exposure standards.

POTENTIAL OCCUPATIONAL EXPOSURES

The following is a list of occupations with specific activities and/or products in which microwave/RF radiation is present and may be a potential hazard.

- Automotive workers
  - Drying of trim base panels
  - Embossing of heel pads to carpets
  - Heat-sealing body interior trim panels
  - Heat-sealing upholstery covers for seats and backs
  - Heat-sealing convertible tops
- Food products workers
  - Finish-drying of "polishing" baked goods
  - Inhibiting enzyme action
  - Melting chocolate prior to tempering
  - Thawing frozen baked goods
- Furniture and wood workers
  - Decking assembly
  - Door lamination
  - Fiberboard fabrication
  - Laminated beams
  - Lumber edge gluing
  - Plywood panel patching
  - Plywood or particleboard scarf gluing
  - Posts
  - Rafters
  - Ski lamination
  - Veneer panel gluing
- Glass fiber workers
  - Drying glass fibers on forming tubes
  - Drying roving packages
  - Drying and curing sizing on machine packages
  - Drying coatings on continuously moving strands
- Paper product workers
  - Correcting moisture profile on continuously moving webs
  - Drying twisted twine packages
  - Drying resin coatings

Paper product workers (cont.)
  Gluing paper
  Heating coating on continuous webs
Plastic heat-sealing workers
  Acetate box covers
  Advertising novelties
  Appliance covers
  Aprons
  Baby Pants
  Beach Balls
  Belts and suspenders
  Blister packages
  Book covers
  Capes
  Check book covers
  Charge cards
  Convertible tops
  Cushions
  Diaper bags
  Display boxes
  Electric blankets
  Food packages
  Fountain pens
  Garment bags
  Gas masks
  Goggles (industrial)
  Hand bags
  Hat covers
  Index cards
  Lampshades
  Liquid containers
  Luggage
  Machine covers
  Mattress covers
  Milk cartons
  Oxygen tents
  Packages
  Pharmaceuticals
  Pillow cases
  Pillow packages
  Plastic gloves
  Pool liners
  Protective clothing
  Rain apparel
  Racquet bags
  Refrigerator bags
  Shoes
  Shoe bags
  Shower curtains

Slip covers
Splatter mats
Sponge backings
Sport equipment
Tobacco pouches
Toys
Travel cases
Umbrellas
Wallets
Waterproof containers
Wire terminal covers

RF/microwave application workers
Advertising — RF excited gas display signs
Ceramics — dry ceramic bodies
Chemical — chemical activation
Electronics — tube aging and testing
Laser — RF excited gas lasers
Medical-diathermy
Scientific equipment — low temperature ashing of samples
Tobacco — dry blended tobacco and dry cigars
Welding — RF stabilized welders

Rubber products workers
Drying latex foams
Gelling latex foams
Preheating prior to molding
Preheating prior to curing latex foams

Textile workers
Drying rayon cake packages
Drying wound packages
Drying impregnated or coated yarns
Drying slasher coatings
Drying continuous webs

REFERENCES

1. Michaelson, S. M. 1971. Biomedical aspects of microwave exposure. Am. Ind. Hyg. Assoc. J. 32:338.
2. Milroy, W. C., and S. M. Michaelson. 1971. Biological effects of microwave radiation. Health Phys. 20:567.
3. Michaelson, S. M., and C. H. Dodge. 1971. Soviet views on the biological effects of microwaves — an analysis. Health Phys. 21:108.
4. Frey, A. H. 1962. Human auditory system response to modulated electromagnetic energy. J. Appl. Physiol. 17:689.
5. Lebovitz, R. M. 1973. Caloric vestibular stimulation via UHF-microwave irradiation. IEEE Trans. Bio-Med. Eng. 20:119.
6. Guy, A. W., C. K. Chou, J. C. Lin, and D. Christensen. 1974. Microwave Induced Acoustic Effects in Mammalian Auditory Systems and Physical Materials. Conf. Biol. Effects Non-Ioniz. Radiat. N.Y. Acad. Sci., New York.
7. Sommer, H. C., and H. E. Von Gierke. 1964. Hearing sensations in electrical fields. Aerosp. Med. 35:834.
8. Baranski, S., and Z. Edelwejn. 1974. Experimental Morphologic and Electroencephalographic Studies on Microwave Effects on the Nervous System. Conf. Biol. Effects Non-Ioniz. Radiat, N.Y. Acad. Sci., New York.

9. Cleary, S. F. 1970. Biological effects of microwave and radiofrequency radiation. Crit. Rev. Environ. Contr. 1:257-306.
10. Dodge, C. H., and S. Kassel. 1966. Soviet Research on the Neural Effects of Microwaves. ATD Rep. 66-133. Library of Congress, Washington, D.C.
11. Presman, A. S. 1965. The effect of microwaves on living organisms and biological structures. Usp. Fiz. Nauk 86:263.
12. Osipov, Y. A. 1966. The Health of Workers Exposed to Radio-frequency Radiation. ATD Rep. 66-133. Library of Congress, Washington, D.C.
13. Livshits, N. N., 1967. On the causes of the disagreements in evaluating the radio-sensitivity of the central nervous system among researchers using conditioned reflex and maze methods. Radiobiology 7:238.
14. Vavala, D. A. 1968. Soviet Research on the Pathophysiology of Ultrahigh Frequency Electromagnetic Fields. Rep. AMD-CR-01-03-68. Brooks Air Force Base, San Antonio, Texas.
15. Presman, A. S. 1968. Electromagnetic Fields and Life. Nauka, Moscow.
16. Gorodetshaia, S. F. 1963. The effect of centimeter radio waves on mouse fertility. Fiziol. Zh. 9:394.
17. Levitina, N. A. 1964. Effect of microwaves on cardiac rhythm of rabbits during local irradiation of body areas. Bull. Exp. Biol. Med. (USSR) 58:67.
18. Gorodetshaia, N. A. 1964. The influence of an SHR electromagnetic field on reproduction, composition of peripheral blood, conditioned reflex activity, and morphology of the internal organs of white mice. In A. A. Gorodetskiy, ed. Biological Action of Ultrasound and Super-high Frequency Electromagnetic Oscillations. pp. 80-91. Acad. Sci., Kiev, USSR.
19. Gordon, Z. V. 1966. Problems of Industrial Hygiene and the Biological Effect of SHF-UHF Electromagnetic Fields. Meditsina, Leningrad, 164 pages.
20. Haduch, S., S. Baranski, and P. Czerski. 1962. The Influence of Ultrahigh Frequency Radio Waves on Human Organism. Presented at 5th European Congr. Aviation Med., London, August 29 to September 2, 1960. In A. G. Barbour and H. E. Whittingham, eds. Human Problems of Supersonic and Hypersonic Flight. Pergamon Press, New York, N. Y. pp. 449-454.
21. Kevorkyan, A. A. 1948. Work with VHF-HF pulsed generators from the standpoint of industrial hygiene. Gig. Sanit. No. 4, 26-30.
22. Letavet, A. A. ed. 1964. Biological Effects of Radio-Frequency Fields. Gig. Tr. Prof. Zabol. No. 2, 170 pages.
23. Letavet, A. A. and Z. V. Gordon, eds. 1960. The Biological Action of SHF-UHF, Gig. Tr. Prof. Zabol. No. 1, 142 pages.
24. Marha, K., J. Musil, and T. Hana. 1968. Electromagnetic Field and Life Environment. Prague, Czechoslovakia, 130 pages.
25. Minecki, L. 1961. The health of persons exposed to the effect of high frequency electromagnetic fields. Med. Pr. 12, No. 4, 329-335.
26. Minecki, L. 1964. Critical evaluation of maximum permissible levels of microwave radiation. Archiv. Za Higijenu Radai: Toksikol., 15, No. 1, 47-55.
27. Osipov, Yu A. 1965. Labor Hygiene and the Effect of Radio Frequency Electromagnetic Fields on Workers. Meditsina Publishing House, Leningrad, 220 pages.
28. Smurova, E. I., T. Z. Rogovaia, S. A. Troitskii, N. S. Lashchenko, and N. D. Melnikova. 1962. Problems of Occupational Hygiene and Health Status of Operators Exposed to the Effects of High Frequency Currents. Gig. Tr. Prof. Zabol. 6, No. 5, 22-28.
29. Smurova, E. I., T. Z. Rogovaia, I. L. Iakub, and S. A. Troitskii. 1964. Industrial Hygiene and the Health of Tube Generator Technicians. Gig. Sanit. No. 12, 27-30.
30. Troyanskiy, M. P., R. I. Kruglikov, R. M. Kornilov, L. B. Petrova Golubenko, and Z. S. Kalashnikova. 1967. Some results of an investigation of the state of health of specialists working with SHF-UHF generators. Voyen Med. Zh., No. 7, 30-35.
31. Drogichina, E. A., N. M. Konchalovskaya, K. V. Glotova, M. A. Sadchikova, and G. V. Snegova. 1966. On the problem of vegetative and cardiovascular disturbances subsequent to chronic exposure to microwave frequency electromagnetic fields. Gig. Tr. Prof. Zabol. 10, No. 7, 13-16.

32. Sadchikova, M. A. 1964. Clinical aspects of changes within the nervous system induced by the action of radio waves of various ranges. Gig. Tr. Prof. Zabol. No. 2, 110-113.

33. Drogichina, E. A., and M. A. Sadchikova. 1964. Clinical syndromes during the action of various radio-frequency ranges. Gig. Tr. Prof. Zabol. No. 2, 105-109.

34. Drogichina, E. A., and M. A. Sadchikova. 1965. Clinical syndromes arising under the effect of various radio frequency bands. Gig. Tr. Prof. Zabol. 9, No. 1, 17-21.

35. Gelfon, I. A., and M. A. Sadchikova. 1960. Protein fractions and histamine of the blood under the influence of SHF-UHF and MF-LF. Trudy NII Gig. Tr. Prof. Zabol. No. 1, 46-49.

36. Gelfon, I. A., and M. A. Sadchikova. 1964 Protein fractions and blood histamine under the action of radio waves of various ranges. Gig. Tr. Prof. Zabol. No. 2, 133-136.

37. Byalko, N. K., and M. A. Sadchikova. 1964. Some biochemical blood indices under the action of centimeter waves. Gig. Tr. Prof. Zabol. No. 2, 137-139.

38. Fukalova, P. P., M. S. Tolgskaya, S. V. Nikogosyan, I. A. Kitsovskaya, and I. N. Zenina. 1966. Research data on the standardization of electromagnetic fields in the short and ultrashort wave ranges. Gig. Tr. Prof. Zabol. No. 7, 5-9.

39. Gordon, Z. V. 1964. Results of a comprehensive study of the biological effects of radio frequency electromagnetic waves and the outlook for further research. Gig. Tr. Prof. Zabol. No. 2, 3-9.

40. Monayenkova, A. M., and M. A. Sadchikova. 1966. Hemodynamic indices under exposure to the action of microwave electromagnetic fields. Gig. Tr. Prof. Zabol. 10, No. 7, 18-21.

41. Nikogosyan, S. V. 1964. A study of cholinesterase activity in the blood serum and organs of animals subjected to the chronic effects of microwaves. Gig. Tr. Prof. Zabol. No. 2, 43-48.

42. Smurova, Ye I., T. Z. Rogovaya, I. L. Yakub, and S. A. Troitskiy. 1966. General health of persons working with HF-LF, VHF-HF, and SHF-UHF generators in physiotherapeutic rooms. Kazan. Med. Zh. No. 2, 82-84.

43. Tolgskaya, M. S., and P. P. Fukalova. 1968. Morphological changes in experimental animals under the action of electromagnetic fields in the HF and VHF ranges. Gig. Tr. Prof. Zabol. No. 9, 37-40.

44. Baranski, S., and P. Czerski. 1966. Investigation of the behavior of corpuscular blood constituents in persons exposed to microwaves. Lek. Wojskowy. No. 10, 903-909.

45. Bartonicek, V., and E. Klimkova-Deutschova. 1964. Some biochemical changes in workers exposed to centimeter waves. Cas. Lek. Cesk. 103, No. 1, 26-30.

46. Chukhlovin, B. A., B. N. Grachev, and I. V. Likina. 1966. The detection of C- and CX- reactive protein in the blood serum during exposure of the organism to SHF-UHF electromagnetic waves. Byull. Eksp. Biol. Med. 61, No. 6, 53-55.

47. Haduch, S., S. Baranski, and P. Czerski. 1960. Research into the influence of high frequency electromagnetic field on human body. Lek. Wojskowy 36, No. 2, 119-126.

48. Krystanov, L., and K. Goshev. 1966. The peripheral blood characteristics of personnel exposed to a superhigh-frequency electromagnetic field. Voen.-Sanit. Delo No. 4, 41-46.

49. Lysina, G. G. 1965. Changes in the morphological composition of blood under the influence of SHF-UHF. Gig. Sanit. No. 6, 95-96.

50. Sokolov, V. V., and M. N. Arfovich. 1960. Changes in the blood under the influence of SHF-UHF on the organism. Gig. Tr. Prof. Zabol. AMN USSR No. 1, 43-45.

51. Susskind, C., ed. 1959. Proc. third annual tri-service conf. on biol. effects of microwave-radiating equipment. 25, 26, and 27 August 1959. 335 pages.

52. Zakhorov, I. V. 1967. The change of metabolic processes in leukocytes during human exposure to low-intensity SHF-UHF and infrared radiation. Dok. Akad. Nauk BSSR 11, No. 12, 1113-1116.

53. Sigler, A. T., A. M. Lilienfeld, B. H. Cohen, and J. E. Westlake. 1965. Radiation exposure in parents of children with mongolism. Bull. John Hopkins University, 117, No. 6, 374-399.

54. Higier, J., and W. Baranska. 1967. Examinations of the genital organs and studies of the menstrual cycle in women working in the field of microwave radiation. Wiad. Lek. 20, 1435-1438.

55. Bereznitskaya, A. N. 1968. Some indicators of the fecundity in female mice irradiated with 10 cm long waves. Gig. Tr. Prof. Zabol. No. 9, 33-37.

56. Gordon, Z. V. 1966. Electromagnetic radio frequency fields as a health factor. Gig. Tr. Prof. Zabol. 10, No. 10, 3-6.

57. Lenko, J., E. Waniewski, and Z. Wochna. 1966. Studies of the effects of microwaves with low-power flux density on the testicles of rabbits. Pol. Tyg. Lek. 39, No. 21, 1475-1477.

58. Nizhnik, G. V. 1956. Viability changes in sexual cells of male rabbits and mice under the action of VHF-HF fields. Zh. Obshch. Biol. 17, No. 4, 311-316.

59. Povzhitkov, V. A., N. V. Tyagin, and A. M. Grebenshchikova. 1961. The influence of an SHF-UHF pulsed electromagnetic field on conception and the course of pregnancy in white mice. Byull. Eksper, Biol. Med. 51, No. 5, 103-107.

60. Marha, K., J. Musil, and H. Tuha. 1968. Electromagnetic fields and the living environment. State Health Publishing House, Prague, Czechoslovakia. Transl. SBN 911302-13-7, San Francisco Press, Inc., San Francisco, California, 1971.

61. Marha, K. 1970. Maximum admissible values of HF and UHF electromagnetic radiation at work places in Czechoslovakia. In S. F. Cleary, ed. Biological effects and health implications of microwave radiation, symposium proceedings. USDHEW, PHS, BRH/DBE 70-2.

62. Cocozza, G., A. Blasio, and B. Nunziata. 1960. Remarks on short-wave embryopathy. Pediatria rivista d'igiene med. e chir. dell'infanzia 68 (No. 1): 7-23. (In Italian.)

63. Minecki, L. 1964. Effect of an RF electromagnetic field on embryonal development. Med. Pracy. 15:307-315. (In Polish.)

64. Rubin, A., and W. J. Erdman, II. 1959. Microwave exposure of the human female pelvis during early pregnancy and prior to conception. Am. J. Phys. Med. 38: 219-220.

65. Carpenter, R. L. 1965. Suppression of differentiation in living tissues exposed to microwave radiation. In Dig. 6th Int. Conf. Medical Electronics and Biological Engineering, Tokyo, Japan, pp. 573-574.

66. Carpenter, R. L., and E. M. Livstone. 1971. Evidence of nonthermal effects of microwave radiation: abnormal development of irradiated insect pupae. IEEE Trans. Microwave Theory and Techniques, Vol. MTT-19, No. 2, pp. 173-178.

67. Van Ummersen, C. A. 1961. The Effect of 2450 Mc. Radiation on the Development of the Chick Embryo. In Proc. 4th Tri-Service Conf. Biological Effects of Microwave Radiation, Vol. 1, pp. 201-219.

68. Van Ummerson, C. A. 1963. An experimental study of developmental abnormalities induced in the chick embryo by exposure to radiofrequency waves. Ph.D. Dissertation, Dep. Biol., Tufts University, Medford, Mass.

69. Dietzel, F. 1974. Effects of electromagnetic radiation on implantation and intra-uterine development of the rat." In the New York Academy of Sciences Conference on the Biological Effects of Non-Ionizing Radiation, New York, February 12-15, 1974, paper #26.

70. Rugh, R., E. I. Ginns, H. S. Ho, and W. M. Leach. 1973. Are microwaves teratogenic? Biologic effects and health hazards of microwave radiation. Proceedings of an international symposium, Warsaw, Poland, October 15-18, 1973, pp. 98-107. Polish Medical Publishers, Warsaw, Poland, 1974.

71. Chernovetz, M. E., D. R. Justesen, N. W. King, and J. E. Wagner. Teratology, survival, and reversal learning after fetal irradiation of mice by 2450 MHz microwave energy. J. Microwave Power 10(4), p. 391.

72. Rugh, R., and M. McManaway. 1976. Can electromagnetic waves cause congenital anomalies? In 1976 International IEEE/AP-S Symposium and USNC/URSI Meeting, Series on Biological Effects of Electromagnetic Waves, Developmental and Mutagenic Effects Session, Paper #1, University of Massachusetts, Amherst, Massachusetts, October 10-15, 1976.

73. Carpenter, R. L. 1958. Experimental radiation cataracts induced by microwave irradiation. Proc. 2nd Annu. Tri-Serv. Conf. Biol. Effects Microwave Energy ASTIA Doc. AD 131-477, pp. 146-166.

74. Carpenter, R. L. 1959. Studies on the effects of 2450 MHz radiation on the eye of the rabbit. Proc. 3rd Annu. Tri-Serv. Conf. Biol. Hazards Microwave Radiat. Equipments (Univ. Calif., Berkeley) Tech. Rep. RADC-TR-59-140, pp. 279-290.

75. Carpenter, R. L. 1962. An Experimental Study of the Biological Effects of Microwave Radiation in Relation to the Eye. (Tufts Univ., Midford, Mass.), Tech. Rep. RADC-TDR-62-131. U.S. Air Force Rome Air Development Center, Rome, New York.

76. Carpenter, R. L. 1970. Experimental microwave cataract: A review. In S. F. Cleary, ed. Biological Effects and Health Implications of Microwave Radiation. Rep. PHS, BRH/DBE 70-2.

77. Carpenter, R. L., D. K. Biddle, and C. A. Van Ummersen. 1960. Opacities in the lens of the eye experimentally induced by exposure to microwave radiation. IRE Trans. Med. Electron. 7:152.

78. Carpenter, R. L. 1961. Biological effects of microwave radiation with particular reference to the eye. Proc. Int. Conf. Med. Electron., 3rd, 1960 pp. 401-408.

79. Carpenter, R. L., and C. A. Van Ummersen. 1968. The action of microwave radiation on the eye. J. Microwave Power 3:3.

80. Carpenter, R. L., E. S. Ferri, and G. J. Hagan. 1974. Some Current Studies on Microwave Ocular Effects. Conf. Biol. Effects Non-loniz. Radiat, N Y. Acad. Sci., New York.

81. Appleton, B., and S. Hirsch. 1974. Experimental Microwave Cataractogenesis. Conf. Biol. Effects Non-Ioniz. Radiat. N.Y. Acad. Sci., New York.

82. Kramar, P. O., A. F. Emery, A. W. Guy, and J. C. Lin. 1974. The Ocular Effects of Microwaves on Hypothermic Rabbits: A Study of Microwave Cataractogenic Mechanisms. Conf. Biol. Effects Non-Ioniz. Radiat. N.Y. Acad. Sci., New York.

83. Weiter, J. J., E. D. Finch, W. Schultz, and V. Frattali. 1974. Ascorbic Acid Changes in Cultured Rabbits Lenses Following Microwave Irradiation. Conf. Biol. Effects Non-Ioniz. Radiat. N.Y. Acad. Sci., New York.

84. Thomas, J. R., E. D. Finch, D. W. Fulk, and L. S. Burch. 1974. Effects of Microwave Radiation on Behavioral Baselines. Conf. Biol. Effects Non-Ioniz. Radiat. N.Y. Acad. Sci., New York.

85. Hunt, E. L., N. W. King, and R. D. Phillips. 1974. Behavioural Effects of Pulsed Microwave Irradiation. Conf. Biol. Effects Non-Ioniz. Radiat. N.Y. Acad. Sci., New York.

86. Sadchikova, A. A., and A. A. Orlova. 1958. Clinical picture of the chronic effects of electromagnetic waves. Ind. Hyg. Occup. Dis. (USSR) 2:16.

87. Czerski, P., K. Ostrowski, M. L. Shore, C. Silverman, M. J. Suess, and B. Waldeskog. 1974. Biologic Effects and Health Hazards of Microwave Radiation. Proceedings of an International Symposium, Warsaw, Poland, October 15-18, 1973. Polish Medical Publishers, Warsaw, Poland.

88. Nonionizing Radiation. Fed. Regist. 37, No. 202, 22162.

89. Kall, A. R. 1968. Final Technical Report on Research Project to Study Radiation Hazards Caused by High Power High Frequency Fields. United States Information Agency. Contract 1A-11651, Washington, D.C.

90. Kall, A. R. 1972. Final Technical Report on Research Project to Study Radiation Hazards Caused by High Power High Frequency Fields. United States Information Agency, Contract 1A-14121, Washington, D.C.

91. Lin, J. C., C. C. Johnson and A. W. Guy. 1973. Power Deposition in a Spherical Model of Man Exposed to 1-20 MHz E-M Fields. IMPI Symp. (oral presentation).

92. S. M. Bawin, R. J. Gavalas-Medici, and W. R. Adey. 1973. Effects of modulated very high frequency fields on specific brain rhythms in cats. Brain Res. 58:365.
93. S. M. Bawin, L. K. Kaczmarak, W. R. Adey, and R. J. Gavalas-Medici. 1975. Effects of modulated VHF fields on the central nervous system. Presented at N.Y. Acad. Sci. Conf. Biological Effects of Nonionizing Radiation, Feb. 12-15, 1974. Ann. N.Y.: Acad. Sci. 247:74.
94. H. Mikolajczyk, Podziaty mitotyczne komórek nabionkowych rogówki oka u zwierzat doswiadczalnych poddanych dziatzniu.
95. J. C. Sharp, L. E. Scheving, and H. M. Grove. Cell division rate of corneal epithelium following exposure to 2450 MHz microwave radiation. Aerosp. Med., to be published.
96. P. Czerski, E. Paprocka-Stonka, and A. Stolarska. 1974. Microwave irradiation and the circadian rhythm of bone marrow cell mitoses. J. Microwave Power 9:31.
97. Prince, J. E., L. H. Mori, J. W. Frazer and J. C. Mitchell. 1972. Cytologic aspect of RF radiation in the monkey. Aerospace Med. 43 (7): 759.
98. Lovely, H. R. H., T. J. Sparks and A. W. Guy. April 15, 1976. In-Vitro Response of Lymphocyte Cultures Exposed to RF Radiation: Progress Report on Feasibility and Determination of Critical Variables. Prepared for the USAF School of Aerospace Medicine, Contract No. F41609-75-C-0021, Brooks AFB, Texas.
99. Stavinoha, W. B., T. M. Arvind, M. A. Medina, D. H. Ross, D. J. Jones and S. T. Weintraub. August, 1975. Research and Reports on Biological Effects of A. F. Transmitter Near Fields. Prepared for USAF School of Aerospace Medicine, Contract No. F41609-74-R-0014, Brooks AFB, Texas.
100. Guillet, R. 1975. Time Course of Adrenal Response in Microwave Exposed Rats. In: USNC/URSI 1975 Annual Meeting—Abstracts, Oct. 20-23, 1975. Boulder, Colorado. (Bioeffects Sessions to be published, 1976).
101. Bollinger, J. N., L. L. Lawson and W. C. Dolle. November, 1974. Research on Biological Effects of VLF Band Electromagnetic Radiation. USAF School of Aerospace Medicine, SAM-TR-74-52, Brooks AFB, Texas.
102. Frazer, J. W. June, 1976. Investigations of the Molecular Basis for Immune Responses in HF band Electromagnetic Fields. Final report prepared for NIOSH, DBBS, PAEB, NIOSH-IA-75-30. Cincinnati, Ohio.
103. Froehlich, J. E. November, 1975. The Extraordinary Dielectric Properties of Biological Materials and the Action of Enzymes. Proc. Nat. Acad. Sci. USA 72(11): 4211-4215.
104. Cody, C. A., A. J. Modestino, P. J. Miller and S. M. Klainer. January 9, 1976. The Detection of RF Damage to High Molecular Weight Biopolymers by Raman Spectroscopy. Prepared for USAF School of Aerospace Medicine, Contract No. F41609-75-C-0043, Brooks AFB, Texas.
105. Bussey, H., J. Frazer and A. Gass. December 14, 1972. Observations on HF Band Power Absorption by Primates. IEEE-GAP- URSI(NSF), Williamsburg, Virginia.
106. Guy, A. W., M. D. Webb and J. A. McDougall. June 15, 1976. Critical Comparisons of RF Field Delivery Methods to Thermal Responses of Models and Experimental Animals. Prepared for USAF School of Aerospace Medicine, Contract No. F41609-75-C-0021, Brooks AFB, Texas.
107. Gandhi, O. P., J. A. D'Andrea, K. Sedigh, and H. W. Simpson. March 31, 1975. Behavioral and Biological Effects of Resonant Electromagnetic Absorption in Rats. Quarterly Report No. 3 pp. 1-10. Electrical Engineering Department, ,Contract No. DAMD 17-74-C-4092, University of Utah, Salt Lake City.
108. Gandhi, O. P., J. A. D'Andrea, B. K. Jenkins, J. L. Lords, J. R. Mijanovich, and K. Sedigh. June 30, 1975. Behavioral and Biological Effects of Resonant Electromagnetic Absorption in Rats. Quarterly Report No. 4, pp. 1-25. Electrical Engineering Department, Contract No. DAMD 17-74-C-4092, University of Utah, Salt Lake City.
109. Conover, D. L., W. H. Parr, E. L. Sensintaffar, and W. E. Murray. 1975. Measurement of Electric and Magnetic Field Strengths from Industrial Radiofrequency (10-40 MHz) Power Sources. In: USNC/URSI 1975 Annual Meeting-Abstracts, p. 101, Boulder, Colorado, Oct. 20-23, 1975. (Bioeffects Sessions to be published, 1976).
110. Moss, C. E.,D. L. Conover, W. E. Murray, and A. N. Kuhre. May 26, 1977. Estimated number of U.S. workers potentially exposed to electromagnetic radiation. 1977 AIHC, May 26, 1977, New Orleans, La.

LASER

The word laser is an acronym for "light amplification by stimulated emission of radiation." Lasers operate in the infrared and ultraviolet as well as visible regions. The name is descriptive of the physical principle involved in the production of the radiation. By stimulating or forcing atoms to emit photons, the resultant laser beam is coherent. This means that the photons in the beam are monochromatic and are in phase with each other. Since the laser beam is highly coherent it diverges slowly, maintains its divergency over a long distance, and has a high radiant exposure. As a result of these properties, laser light differs considerably from visible light.

At one time shortly after the development of the first working model in 1960, the laser was referred to as a solution looking for a problem. This situation has changed. By 1975 the development and marketing of new laser devices had resulted in the availability of almost 2500 models from 175 manufacturers and distributors. The most common lasers are shown in Table 10.

HARMFUL EFFECTS

The laser by virtue of its design is able to concentrate a large amount of energy in a small cross-sectional area. Consequently, individuals working with such devices encounter a potential hazard. The critical organs are the eye and skin and the resulting biological effects are similar to those produced by conventional optical radiation sources. Since energy must be absorbed to produce an effect, the degree of injury depends upon the wavelength of the laser and the capacity of the tissue to absorb energy of that particular wavelength.

The primary hazard from laser exposure is ocular damage. Overexposure of skin varies from a mild erythema to blisters and charring. Chronic or repeated exposures to laser radiation may have a long-term effect, but this is normally discounted.

Infrared radiation (700-1400 nm) has also been implicated as a cataractogenic agent. Overexposure to UV laser radiation can result in keratoconjunctivitis. Cataracts can be induced by UV lasers operating in the 300-400 nm range. Infrared lasers (1400 nm to 1 mm)present a corneal hazard only.

PERSONAL PROTECTIVE METHODS

If the radiation levels are kept below those injurious to the eye, other tissues will not be harmed. The thresholds for skin and ocular damage are the same for both UV radiation and for IR (1400 nm – 1mm)ranges. It is assumed that both organs are equally sensitive. The visible and near IR wavelengths (400-1400 nm) are readily transmitted through the ocular media to the retina. Not only is this radiation transmitted, it is focused by the lens onto the fovea centralis which concentrates the energy onto a very small spot.

Thus, in this spectral region, the eye (retina) is far more sensitive

Table 10. Common laser devices and applications.

Type	Wavelength(s)	Applications
Argon (Ar)	458-515 nm	alignment surveying instrumentation halography photocoagulation
Carbon dioxide (CO_2)	10.6 μm	material processing optical radar instrumentation surgery techniques
Dye	variable	instrumentation
Gallium arsenide (GaAs)	850-950 nm	instrumentation ranging intrusion detection communications
Helium cadmium (HeCd)	325, 442 nm	alignment surveying
Helium neon (HeNe)	632.8 nm	alignment surveying halography ranging intrusion detection communications
Neodymium glass (Nd glass) Neodymium YAG (Nd YAG)	106 μm	material processing instrumentation optical radar surgery
Ruby	694.3 nm	material processing holography photocoagulation ranging

than the skin by several orders of magnitude, and even a diffuse reflection from a high power laser can present an ocular hazard. An action spectrum has been recently developed to account for the variation in retinal sensitivity with wavelength for exposure times greater than 10 seconds. The minimum threshold dose for retinal lesions occurs at 440 nm and is thought to be due to a photochemical process rather than to a thermal mechanism as in wavelengths greater than 500 nm.

POTENTIAL OCCUPATIONAL EXPOSURES

Lasers are used in many diverse situations such as drilling holes in metals and baby bottle nipples, cutting diamonds, aligning wings on airplanes, repairing detached retinas, and taking three-dimensional pictures.

BIBLIOGRAPHY

American National Standards Institute. 1973. Safe Use of Lasers. ANSI Z-136.1, New York, N. Y.

Boettner, E. A., and J. R. Wolter. 1962. Transmission of the ocular media. Invest. Ophthalmol. 1:776.

Commission Internationale de E'Cairage (CIE). 1970. International Illumination Vocabulary. CIE, Paris, France.

Duke-Elder, S. 1974. Textbook of Ophthalmology Injuries. C. V. Mosby Co., St. Louis, Mo.

Fitzpatrick, T. B., et al., ed. 1972. Sunlight and Man. University of Toyko, Tokyo, Japan.

Geeraets, W. J., and E. R. Berry. 1968. Ocular spectral characteristics as related to hazards from lasers and other light sources. Am. J. Ophthalmol. 66:15.

Ham, W. T., et al. 1973. Ocular hazard from viewing the sun unprotected and through various windows and filters. Appl. Opt. 12(9):2122.

Jacquez, J. A., et al. 1955. Spectral reflectance of human skin in the region 235-700mμ. J. Appl. Physiol. 8:212-214.

Matelsky, I. 1968. The Non-ionizing radiations. In L. V. Cralley et al., eds. Industrial Hygiene Highlights, Vol. 1. Industrial Hygiene Foundation of America, Inc., Pittsburgh, Pa.

Sliney, D. H. 1972. Non-ionizing radiation. In L. V. Cralley et al., eds. Industrial Environmental Health, The Worker and the Community. Academic Press, New York, N. Y.

Sliney, D. H., and B. C. Freasier. 1973. Evaluation of optical radiation hazards. Appl. Opt. 12:1.

Turner, H. S. 1972. The Interaction of Infrared Radiation with the Eye. A Review of the Literature. Ohio State University Research Foundation, NASA-Cr-128407, Columbus, Ohio.

Tyler, Paul E. 1974. Conference on biologic effects of nonionizing radiation. Annals N. Y. Acad. Sci. 247:44.

U. S. Department of Health, Education, and Welfare, Public Health Service, Center for Disease Control, National Institute for Occupational Safety and Health. 1972. Occupational Exposure to Ultraviolet Radiation: Criteria for a Recommended Standard. HEW Pub. No. (NIOSH) HSM-049-71-36, Cincinnati, Ohio.